METEOROLOGICAL SUPPORT FOR UK NAVY OPERATIONS

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1. INTRODUCTION

Atmospheric refraction effects are well known to the Royal Navy (RN) as a factor that can dramatically affect the performance of radars, giving extended ranges in ducting conditions and reduced ranges in sub-refracting conditions. The RN currently use IREP S (Integrated Refractive Effects Prediction System) operationally to predict radar performance. This system uses a single radiosonde ascent to represent the propagating environment. This is then used to calculate the predicted radar coverage.

Since 1990 the RN have also been using a PC-PEM (Parabolic Equation Method), which was developed by Rutherford Appleton Laboratory, in addition to IREPS to support radar propagation and modelling and range prediction. This model is described by Craig and Levy (1989) and was found to give reliable propagation predictions.

The accuracy of both the PC-PEM and IREPS models is limited by the quality of the available meteorological data. Radiosonde ascents are routinely made at 6 hourly intervals (4 per day) from 8 locations around the UK (in addition to several sited in Europe). No data are routinely available over the sea, and the spatial resolution is relatively poor. This means that the most appropriate ascent available for a specific forecast of radar propagation may be hundreds of kilometres from the operating area, and several hours old. To overcome these problems a study was carried out to investigate the possibility of using UK Met Office Mesoscale Model output, in conjunction with a PE model for forecasting radar performance.

2. THE MET OFFICE MESOSCALE MODEL

The Met Office Mesoscale Model (MM) forms an integral part of the operational Unified Model (UM) suite which is run routinely by the Met Office at Bracknell. The UM suite, which has been described by Cullen (1993), consists of global, limited area and Mesoscale versions of the Unified Model. The Mesoscale version of the model has a grid length of 0.15° (about 17 km) on a 92x92 grid covering an area of about 1500 km $\times$ 1500 km and has 31 levels up to 4.6 mb, In the lower atmosphere, which is the region of interest for radar propagation predictions, there are 11 levels below 1500 m. These are shown in Table 1, where the heights are approximate since the levels are defined using a hybrid sigma/pressure co-ordinate system, The MM can be run for a number of relocatable windows, a standard version is run for the UK, and two ‘crisis-area’ models can also be run at the same time. Currently the model is run for the Gulf and the region around the former Yugoslavia

Level	Height m	Level	Height m
0	0	6	435
1	10	7	595
2	40	8	770
3	100	9	955
4	190	10	1155
5	300	11	1365

Table 1. Approximate heights of levels below 1500 m in the Met Office MM.

A joint trial between the Met Office and the Royal Navy Fleet Weather and Oceanographic Centre (FWOC) was carried out in the summer of 1994, in the Adriatic, to assess the usefulness of the MM forecasts for predicting radar ducting. Full details of this trial are given in Tunnicliffe *et al. (1994).*

3. PREDICTION OF PROPAGATION CONDITIONS

During the period of the trial radiosonde ascents were made from a ship at sea at OOZ and 12Z. These data were then compared with MM data for the nearest grid point to the ship. Initially the propagation conditions at low levels were diagnosed from both the model and actual profiles, and the results were compared. Comparisons were made for (i) surface evaporation ducts and (ii) other ducts,

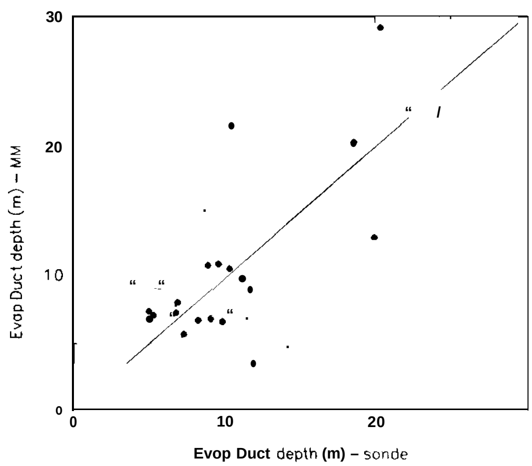

Figure 1. Comparison of derived evaporation duct depths from radiosonde and MM data.

Evaporation ducts were diagnosed from the radiosonde profiles using the evaporation duct model in the IREPS PC-2. O software, This gave duct depths ranging from 4 m to 22 m. Evaporation duct depths were similarly diagnosed from the MM data by inputting the predicted surface parameters. The results gave a mean depth error of +0.3 m, with an rms error of 4.7 m. These results, shown in Figure 1, suggest that reasonable predictions of evaporation duct depth can be determined from the MM.

The other ducts considered were those ducts which were all, or part, found below 1000 ft; this being the region of the atmosphere which is most important to RN radar operations. The results are summarised in the matrix in Table 2. This shows that ducting conditions occurred on 82°/0 of all occasions, Clearly the MM is capable of predicting low level ducts, although it often misrepresented the duct structure since it tended to predict simple surface ducts rather than the S-shaped structure which generally occurred.

The MM forecasts were also compared to predictions based on persistence (i.e. assuming conditions are unchanged from the previous radiosonde ascent when it was no more than 24 hours old). The predictions based on persistence have a very good 'hit rate', however they exhibit a much larger 'false alarm rate' than the MM forecasts. The forecast methods were compared by means of a 'skill' parameter, where the skill score lies in the - 100°/0 to + 100°/0, where O would result from a random forecast. The skill score from the above cases for persistence predictions is -4°/0, whereas the skill score for the MM predictions is 45%.

MM	Radiosonde				
	Nil	Simple	S-Shaped	Elevated	All
Nil	4	0	7	1	12
Simple	1	0	8	0	9
S-Shaped	0	0	5	0	5
Elevated	0	0	1	1	2
All	5	0	21	2	28

Table 2. Ducting conditions matrix for MM forecasts

3.1 RADAR RANGE PREDICTIONS

Whilst the above results have examined the capability of the MM for refractivity forecasting and determining the propagation conditions, it can be argued that it is operationally more relevant to judge the MM on its usefulness for making radar range predictions. Therefore range predictions were made with the RN's version of the PC-PEM using both the predicted (mm) and actual conditions,

Figure 2 shows examples of the predictions from PC-PEM for midday on 3 June 1994. The three grey shades correspond to detection ranges for small, medium and large targets. The example on the left shows a prediction using an actual ascent, In this case a strong duct some 580 ft deep was evident, giving extended ranges. The MM forecast suggested a duct of a similar depth, although the predicted duct was much weaker than that observed

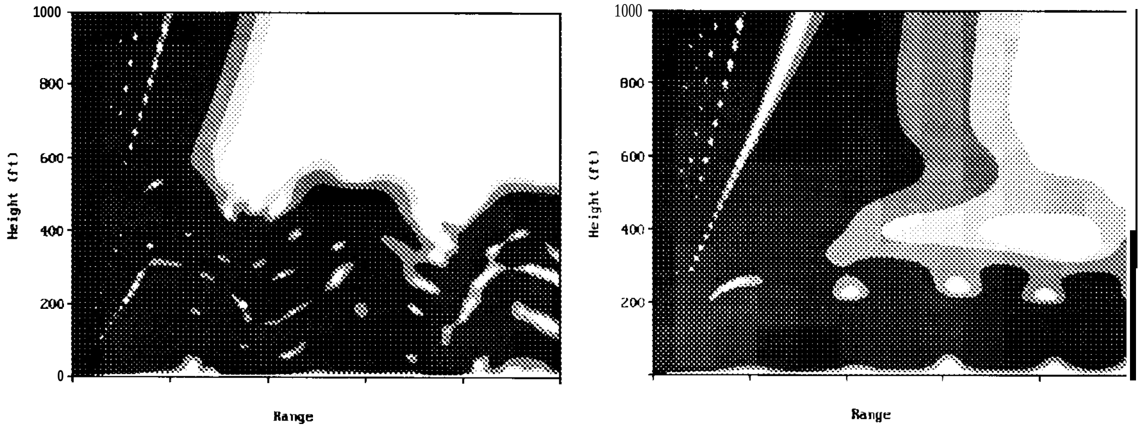

Figure 2. PC PEM coverage displays based on (left) measured radiosonde data and (right) MM forecast

3.2 RANGE DEPENDENCY

So far the refractivity predictions from the MM have only been compared to single point measurements made from a ship. However, in such a coastal environment the structure of the boundary layer will be modified across the land/water transition. This may lead to significant range-dependent behaviour such that the radar coverage predictions based on a single profile can sometimes be misleading. The coverage of a ship-borne radar looking towards land (and also a coastal radar looking out to sea) will often be affected by a range dependent environment. This includes both the effect of the changing surface (sea/land), terrain effects (Levy, 1993) and a range dependent atmospheric structure.

An example illustrating the type of range dependent behaviour that can be predicted by the MM is given here. In this case, from midday on 3 June 1994, the MM prediction showed good agreement with the measured profile from the ship. The MM suggested a surface based duct 190 m deep and the observations showed a surface S-shaped duct of 177 m depth, There was also a shallow near surface evaporation duct embedded within the ducting layer. Figure 3 shows the modified refractivity profiles along a line crossing the Dalmatian coast. The profiles have been offset by 100 M-units for clarity. This line, defined by 3 grid points, was about 96 km long and virtually perpendicular to the coastline, which coincides with the right-most profile in Figure 3. Here the model coast line is quite simple, whereas the actual coastal region in this area is a complex network of islands and peninsulas.

In this example the structure of the ducting layer in the MM changes significantly as the land is approached. The simple surface duct becomes S-shaped as the base of the trapping layer rises and the duct detaches from the ground (i. e. it becomes an elevated duct) before the coastline is reached. The duct also weakens as the coast is approached. On this occasion the whole area was under a large anticyclone extending across the Mediterranean and the Black Sea, with a moderate SSW'ly breeze (i.e. blowing along the coastline).

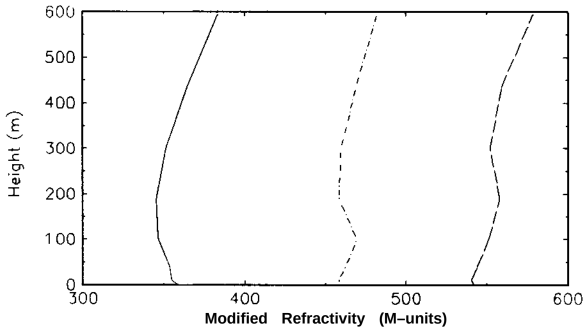

Figure 3. MM predicted modified refractivity profiles along a line perpendicular to the coast line (for midday on 3 June 1994)

Although the above shows that the MM is capable of resolving range dependencies in a coastal environment, the accuracy of the predictions is unknown at present, since there are no measurements with which to compare the MM. To overcome this problem the Meteorological Support Group (MSG) of the MOD have sponsored aircraft flights by the Met. Office Meteorological Research Flight (MRF) C-130 Hercules in coastal areas. The MRF C-130 is a fully instrumented Hercules, which is capable of measuring a full range of meteorological parameters including; temperature, dew point, pressure, wind speed and direction, cloud physics, radiation, and atmospheric chemistry. It has a long (12 hour) endurance; a 5000 km range and a ceiling of 10000 m.

Two flights will be carried out over the south east coast of England (East Anglia), as shown in Figure 4. This area has been chosen because of the proximity of the coastal radiosonde station at Hemsby. The data from the radiosondes will give information on the structure of the atmosphere over the land, The C-13 O will measure the structure of the atmosphere over the sea and coastal regions. The flight will include profiles over the sea from above the boundary layer to 50 ft above sea level. 50 km straight and levels runs will also be carried out perpendicular to the coast. These will be carried out at various heights, ranging from 100 ft above sea level to the top of the boundary layer. Runs above 250 ft will be continued for 30 km inland (250 ft is the lowest permitted altitude for flights over land).

In addition to the two flights off the south east coast of England, the MSG are also sponsoring 20 flying hours for a European experiment called Variability of Coastal Atmospheric Processes (VCAP). This experiment is part of the Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe (STAAARTE) programme. The flights will follow a similar pattern to the UK flights, but they will be located off the coast of Sweden. This experiment will take place in April/May 1997. The operating area for the VCAP flights are also shown in Figure 4.

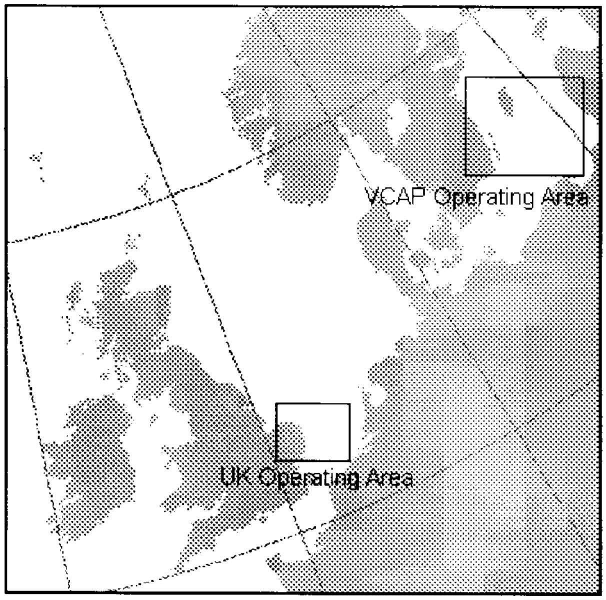

Figure 4. C-13 O operating areas for UK and VCAP flights

These flights will enable the detailed measurement of the structure of the coastal environment to be made. The results can be compared with the MM output to determine if the MM performs sufficiently well in coastal regions. The results will also be used to determine how to interpolate between MM grid points in littoral environments (see section 4).

4. ENVIRONMENTAL ELECTROMAGNETIC MODELLING SYSTEM

The above results have illustrated that the MM can be used in conjunction with a PE model to give reliable predictions of the propagation environment. Additionally the MM is able to model changing refractivity conditions in littoral regions. However, the RN have an operational requirement for a fast, accurate RF/microwave prediction system able to model propagation in the littoral environment over mixed (land/sea) paths. Neither the IREPS nor the PC-PEM models meet this requirement. The IREPS model cannot take account of a range dependent environment, and PE models are generally too slow to be used operationally in real-time.

To overcome this problem, the RN have embarked on a project to develop a timely, high fidelity, fully range dependant electromagnetic/electro-optic modelling system. The new model, called EEMS (Environmental Electromagnetic Modelling System), is being developed in collaboration with the Maritime Warfare Centre (Gosport), Signal Sciences Ltd (UK) and the Meteorological Office. EEMS will include an advanced RF propagation model which can take account of a range dependent environment, and it will have links to a terrain database. To overcome the problem of the amount of processing time required for full PE models, a combined PE/ray optics model has been developed (by Signal Sciences Ltd.). Only regions where the full detail is required are processed with PE models, with the other regions being treated with simpler and faster ray optics techniques. This hybrid model is described in more detail by Levy and Craig (1996).

The Met. Office are developing a meteorological pre-processor for EEMS. MM data for the Adriatic is being used for development purposes. The ideal position would be to have all model grid points at all levels for the whole model area at 6 hour intervals to T+24. However, this would involve vast amounts of data which could not be transmitted in a timely manner. As a compromise, a subset of the MM area will be extracted; either a small area, or a larger area with a coarser resolution (i. e. every other grid point) would be available. Data retrieval will be carried out via a PC program, A prototype of the user interface is illustrated in Figure 5. The user will be able to use the mouse to locate the ship's position and the bearing of interest (the 'threat axis').

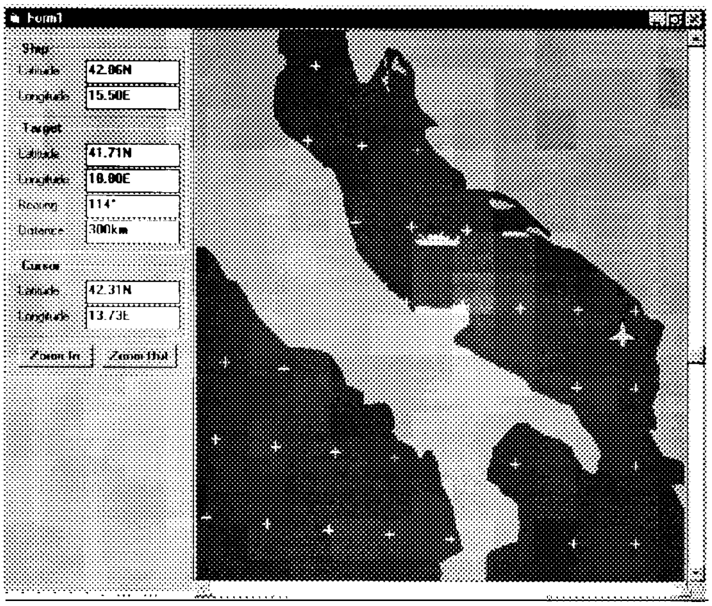

Figure 5. Prototype of the user interface for the EEMS met. pre-processor.

Environmental profiles will be calculated for points at specified intervals along the threat axis. Initially the nearest MM grid point to each point on the threat axis will used. This method should give a good indication of the range dependency along the threat axis. In littoral regions, this approach may not give the best representation. For example, a point on the threat axis may be over the sea while the nearest grid point may be over the land. In this case, the environment may differ greatly from the specified point on the threat axis to the nearest grid point.

To overcome this problem, it is planned to include an interpolation scheme between the surrounding grid points to give a series of derived profiles which lie along the line of the threat axis. Some of the possible interpolation techniques which are being considered are;

(i) a simple linear or quadratic interpolation, and
(ii) the Refractivity Structure Matching Algorithm (RSMA), developed by the Naval Research Laboratory (NRL) and Analysis& Technology, Inc, Monterey.

It is possible that the best method may differ for different environmental conditions. For example, in a truly maritime environment, the boundary layer will not vary greatly from one grid point to another, so a simple linear interpolation between the points may prove to be sufficient. However in the coastal regions, the boundary layer is likely to change significantly from one grid point to another, especially if the grid spacing spans the sea/land interface. In these cases a more complex interpolation, perhaps linked with the RSMA technique may be necessary. The results from the C-130 flights will be used to determine the most appropriate interpolation technique for the MM in the various environments.

5. REFERENCES

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